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SPECIFICATION

OPTICAL ISOLATOR WITH REDUCED INSERTION LOSS AND MINIMIZED POLARIZATION MODE DISPERSION

RELATED APPLICATIONS

This application claims the benefit of US Provisional Application 60/240,441, filed October 13, 2000 (Attorney Docket No, NFCS-014P).

BACKGROUND

Field

The present disclosure relates generally to fiber optics, and in particular, to optical isolators.

The Prior Art

Background

The optical isolator is an element of modern optical communication networks. Optical isolators allow light to travel in one direction, while blocking light traveling in an opposite direction. The ever-increasing speeds of today's optical networks have placed higher performance demands on optical isolators. Today, network speeds of 40 Gb/s and higher are required for many applications. Polarization Mode Dispersion (PMD), Polarization Dependent Loss (PDL), and insertion loss are important characteristics which must be minimized in any high-speed optical communication system.

Figure 1 shows a prior art optical isolator as described in U.S. Patent No. 4,548,478 and assigned to Fujitsu Limited of Kawasaki of Japan. The optical isolator 100 of FIG. 1 includes an optical fiber 102 from which an incident light beam 104 is launched into a first lens 106. Two birefringent plates 108 and 112 are placed on either side of a 45° Faraday rotator 110 within the path of light beam 104. When light passes through the birefringent plate 108 in a forward direction (left to right), the angle of refraction of an ordinary ray (o-ray) and an extraordinary ray (e-ray) are different, so that a polarization separation is realized. The o- and e-rays are then directed into the Faraday rotator 110, where their planes of polarization are rotated 45°. The o- and e-rays are then directed into birefringent plate 112, which is configured to transmit the e- and o-rays in a parallel manner. These parallel beams are then focused into optical fiber 120 by second lens 118. However, light traveling in a reverse direction, (from right to left) will have its

e- and o- rays refracted in a different manner by the birefringent plates, causing the rays not to be focused into optical fiber 102 by first lens 104.

While the optical isolator 100 of FIG. 1 performs its intended function, certain disadvantages have become evident. For example, the displacement of the e- and o-rays in space (known as walk-off) introduces insertion loss and Polarization Dependent Loss (PDL) into the isolator in the forward path. Additionally, the fact that the two beams are traveling different optical paths results in the two beams having different velocities when passing through the isolator. This results in the device not being PMD-free that may not be acceptable for modern optical communication systems.

BRIEF DESCRIPTION

A portion of an optical isolator herein referred to as an optical isolator core is disclosed which may include: a first polarizer configured to receive incident light traveling along a path and refract said incident light into o-rays and e-rays. A rotator is disposed along the path and configured to rotate the polarization planes of the o-rays and e-rays. A second polarizer is disposed along the path and has an optic axis 45° apart from, and a wedge cutting direction aligned as in , the first polarizer.

A correction element of birefringent material having a length and an optical plane within the optic axis of the second polarizer is provided. The correction element has an

optical axis angle and length that are chosen to compensate for PMD and walk-off introduced by the first and second polarizers.

An additional aspect of the disclosed optical isolator core is provided which includes a first polarizer configured to separate light incident in the forward direction into at least one o-ray and at least one e-ray; a polarization rotator; a second polarizer; and a correction element having a crystal optic axis which lies in a plane defined by the at least one e-ray and said at least one o-ray.

A further aspect of the disclosed optical isolator core is provided in which the at least one o-ray and at least one e-ray travel through the isolator separated by a predetermined walk-off distance. The correction element is configured to substantially reduce the walk-off distance between the at least one o-ray and said e-ray exiting the second polarizer. Additionally, the correction element is configured to substantially eliminate the first order polarization mode dispersion, namely DGD (Differential Group Delay).

Further aspects of the disclosed optical isolator core include the o-ray and one e-ray intersecting at an angle β within the correction element. The correction element has a physical length of L. The disclosed optical isolator may be configured so the o-ray and e-ray exit the second polarizer separated by a walk-off distance that is approximately equal to the length L multiplied by the tangent of angle β.

The correction element of the disclosed optical isolator may have a tangent of angle β defined as:

$$\tan(\beta)=\frac{\left(n_e^2-n_o^2\right)\sin(\alpha)\cos(\alpha)}{n_o^2\sin^2\alpha+n_e^2\cos^2\alpha}$$

A method for receiving light passing through an optical isolator in a forward direction through the disclosed isolator is disclosed. The method may comprise separating the light traveling in a forward direction into at least one o-ray and said at least one e-ray; rotating the polarization of the o-ray and one e-ray; refracting the o-ray and the e-ray such that they are in substantially parallel paths; and passing the o-ray and the e-ray through a correction element having an optic axis in a plane defined by the substantially parallel o-ray and e-ray exiting the second polarizer.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

Figure 1 is a diagram of a prior art optical isolator.

Figure 2 is a functional diagram of the disclosed optical isolator core.

Figure 3 is a detailed diagram of a correction element.

Figure 4 is an isometric diagram of a correction element.

Figure 5 is a functional diagram of the disclosed optical isolator core operating as an isolator showing light traveling in the reverse direction.

Figure 6 is a diagram of a complete isolator unit.

DETAILED DESCRIPTION

Persons of ordinary skill in the art will realize that the following description is illustrative only and not in any way limiting. Other modifications and improvements will readily suggest themselves to such skilled persons having the benefit of this disclosure.

Figure 2 is a diagram of an improved isolator core 200 which shows incident light being applied to isolator core 200 along a path 204. Isolator core 200 includes a first polarizer 206 having a wedge angle θ_1. Isolator core 200 is preferably disposed within path 204. In one aspect of the disclosed isolator core, the wedge angle θ_1 of polarizer 206 ranges from approximately 0° to approximately 20°. Typically, a wedge angle of approximately 8° is used for high birefringence materials such as YVO_4, and TiO_2, and approximately 13° to 15° for low birefringence materials such as $LiNbO_3$. Polarizer 206 also has an optic axis C_1 having an angle γ_1.

Polarizer 206 may be fabricated from birefringent materials known in the art. Preferred materials include $LiNbO_3$, YVO_4, and TiO_2 such that the polarizer 206 will separate the incident light into o-rays (shown as a solid line for the condition where $n_e>n_o$) and e-rays (shown as a dashed line) as is known in the art.

Isolator core 200 also includes a rotator 208 disposed within path 204 and configured to receive the o- and e- rays from polarizer 206. Rotator 208 may comprise any non-reciprocal optical element known in the art such as a garnet Faraday rotator for rotating the planes of polarization of the incident o- and e-rays at a predetermined angle, such as approximately 45°.

Isolator core 200 further includes a second polarizer 210 disposed within path 204. Polarizer 210 also has an optic axis C_2 having an angle γ_2. In one aspect of a disclosed isolator core, the angle γ_2 of polarizer 210 is approximately 45° apart from the angle γ_1 of the polarizer 206.

Polarizer 210 may be fabricated from any birefringent material known in the art, such as $LiNbO_3$, YVO_4, and TiO_2. The polarizers 206 and 210 are preferably formed from the same material.

Polarizer 210 is disposed in path 204 to receive the o- and e-rays from rotator 208, and is optically configured using methods known in the art such that when the o- and e- rays exit, they are refracted and aligned in a substantially parallel manner.

The two polarizers may have optic axes C1 and C2 that are 45° apart. Additionally, the difference between the two optic axes may equal approximately 45°. In another aspect of the disclosed isolator core, the angles θ of both polarizers 206 and 210 are substantially equal.

Isolator core 200 further includes a correction element 212, shown in more detail in Figure 3, having a length of L, and an optic axis C having an angle α. Correction element 212 is disposed in path 204 to receive the o- and e-rays from the polarizer 210 of Figure 2. Correction element 212 may be fabricated from birefringent materials known in the art, such as $LiNbO_3$, YVO_4, and TiO_2.

Correction element 212 may be optically configured according to the diagram of Figure 3 and the equations below. The incident o- and e-rays are separated by a walk-off distance d when they are received by correction element 212, and are refracted such that a predetermined angle β is formed.

Additionally, referring to Figure 3, by optimizing the optic axis angle α and the length L, both the PMD and the walk-off can be corrected at the same time while the o- and e-rays may be recombined at a distance L. As can be seen by inspection of FIG. 3, the e-ray and o-ray may be refracted by correction element 212 such that the rays intersect at a point proximate to the distal face 215 of correction element 212. It is to be understood that the correction element 212 may comprise a wide variety of shapes other than that shown in FIG. 3. In one aspect of the disclosed isolator core, the faces 213 and 215 are substantially parallel.

Figure 4 is a three dimensional diagram of a correction element 212. FIG. 4 is provided to show how the optical plane P and the angle α of the optic axis C of correction element 212 are configured in one aspect of the disclosed isolator core. As can be seen by inspection of FIG. 4, the optical plane P of correction element 212 is

preferably chosen such that it lies in a plane formed by the incident o- and e-rays. The angle α of optic axis C preferably lies within the optical plane P. The optical plane P may be aligned with or perpendicular to the optic axis of the second polarizer 210.

Correction element 212 may be configured by utilizing the following equations:

The tangent of angle β as shown in FIG. 2 may be found from:

$$\tan(\beta) = \frac{\left(n_e^2 - n_o^2\right)\sin(\alpha)\cos(\alpha)}{n_o^2 \sin^2\alpha + n_e^2 \cos^2(\alpha)}$$

The relationship between the walk-off distance d, length L, and the angle β can be found from:

$$d = L \bullet \tan(\beta)$$

The PMD may be found from:

$$PMD = \frac{n_e'(\alpha)L - n_o L}{c}$$

where c is the speed of light in vacuum, and where:

$$n_e'(\alpha) = \frac{n_o n_e}{\sqrt{n_o^2 \sin^2\alpha + n_e^2 \cos^2\alpha}}$$

We can solve the above equations to solve for the desired variable.

For example, $L \approx 0.2$ to 0.5 mm, and $\alpha = 10°$ to $15°$

Figure 5 is a diagram of an isolator core 500 showing the isolator core functioning as an isolator when light is incident in the reverse direction, traveling from right to left. As can be seen by inspection of FIG. 5, when light is incident from the right, the o- and e- rays will not be recombined when they exit polarizer 206.

Figure 6 is a diagram of a isolator 600 including first polarizer 206, rotator 208, second polarizer 210, and correction element 212 forming an isolator core as shown and described above.

Isolator 600 may further include a first collimator 604 having a fiber pigtail 606 and a coupling lens 608, and a second collimator 605 having a fiber pigtail 612 and a coupling lens 610, all of which may be formed from materials known in the art. It is contemplated that any optical fibers known in the art may be utilized with the disclosed optical isolator.

It is further contemplated that the disclosed isolator may be fabricated in a wide variety of advantageous manners. For example, the isolator 600 may also include a magnetic ring enveloping the first polarizer 206, rotator 208, second polarizer 210, and correction element 212, further defining an isolator core. The magnetic ring may be formed from materials known in the art. Finally, the isolator 600 may be encapsulated in an outer housing and sealed as is known in the art.

The above equations and disclosed aspects result in an optical element in which the walk-off distance may be kept to a minimum, thereby minimizing polarization dependent loss. Furthermore, the correction element of the present disclosure allows for the e- and o-rays to travel optical paths that are substantially equal in length, further reducing the effects of PMD and DGD as well as reducing insertion loss.

It is contemplated that the disclosed optical isolator and isolator core may be advantageously deployed in a variety of applications where low-loss elements are needed. For example, the disclosed isolator may be used in critical long-haul applications such as optical amplifiers, where low PMD and DGD are critical. The correction element of the present disclosure may also be advantageously used in other passive optical components such as circulators and integrated polarization beam splitters and combiners.

While embodiments and applications of this disclosure have been shown and described, it would be apparent to those skilled in the art that many more modifications and improvements than mentioned above are possible without departing from the inventive concepts herein. The disclosure, therefore, is not to be restricted except in the spirit of the appended claims.